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ARTIFICIAL PROPAGATION OF SHAD

By GLEN C. LEACH

DEPARTMENT OF COMMERCE

Bureau of Fisheries Document No. 981

DEPARTMENT OF COMMERCE
BUREAU OF FISHERIES
HENRY O'MALLEY, Commissioner

ARTIFICIAL PROPAGATION OF SHAD

By GLEN C. LEACH
Assistant in Charge of Fish Culture

APPENDIX VIII TO THE REPORT OF THE U. S. COMMISSIONER
OF FISHERIES FOR 1924

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ARTIFICIAL PROPAGATION OF SHAD[1]

By Glen C. Leach, *Assistant in Charge of Fish Culture*

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DESCRIPTION

The shad is anadromous, a member of the herring family (Clupeidæ), and is closely allied to the river herring or alewife (Pomolobus). Two species, *Alosa vulgaris* and *A. finta,* are indigenous to European waters, while in American waters three species have been recognized. Two of these, *A. alabamæ,* of certain streams of the Gulf of Mexico, and *A. ohioensis,* of the Ohio River, have little or no commercial value and are not artificially propagated; but the third, *Alosa sapidissima,* is the shad of commercial importance, and it is with this species that this paper deals.

The shad is the largest, best known, and most valuable member of the herring family in the United States. Its sides are silvery, and it is white below. When fresh from the ocean, it is dark bluish or greenish above, but this is largely lost after the fish enters fresh water at spawning time. There is a dark blotch behind the gill opening, frequently succeeded by a series of similar spots in one or two longitudinal rows, which are more plainly to be seen after the scales have been removed. The ventral fins often have black or dusky edges. The body is covered with large, silvery scales, easily detached, 52 to 64 of which occupy the lateral line. The ventral edge of the body is provided with bony scutes or modified scales giving the abdominal line a strongly serrated appearance. Twenty-two to twenty-four of these scutes occur in advance of the ventral fins and 12 to 16 behind them. The fins are small and weak; the dorsal is much nearer

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[1] Appendix VIII to the Report of the U. S. Commissioner of Fisheries for 1924. B. F. Doc. No. 981. This document represents a revision and enlargement of the chapter on "The shad" from A Manual of Fish Culture, Based on the Methods of the United States Commission of Fish and Fisheries, with Chapters on the Cultivation of Oysters and Frogs, revised edition, published in 1900.

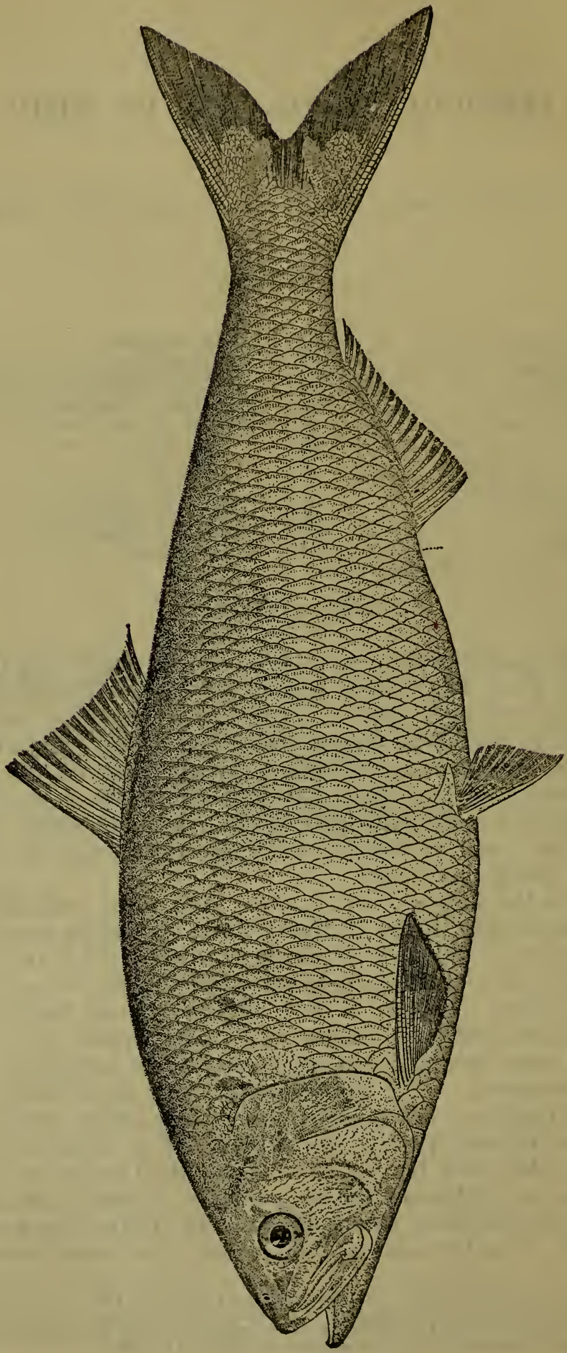

FIG. 1.—The shad (*Alosa sapidissima*)

the snout than the base of the caudal and is composed of 17 to 19 rays; the anal has 19 to 21 rays. The body is comparatively deep and compressed, the depth varying with sex and spawning condition. The head is also deep, with the free portion of the cheek deeper than long. The jaws are about equal in length, the lower one fitting into a deep notch on the tip of the upper in adult fish. Teeth are present in the young, but are not found in the jaws of the adult. The gill rakers are long, slender, and numerous, numbering from 93 to 120 on the first arch in adult fish. The numerous pinlike bones are chiefly several series of intermuscular bones, which support the muscle segments above the ribs. The peritoneum is white, and on the side of each body wall lies a narrow strip of dark muscle.

The shad may readily be distinguished from the other clupeoids with which it is frequently associated in the rivers. In all of these, except the hickory shad or hickory jack (*Pomolobus mediocris*), the cheek is longer than deep. In the latter two species it is about as long as deep, but the projecting jaw closely resembles that of the shad in shape. The river herrings, or alewives, are much smaller than the shad, have fewer and shorter gill rakers and larger eyes. In the branch herring (*P. pseudoharengus*) the peritoneum is pale, while in the glut herring (*P. æstivalis*) it is black.

Perhaps the most prominent and constant distinguishing marks, particularly in the young, where other differences are frequently less pronounced, are the differences in the shape of the cheek and the structure of the lower jaw. In the shad the cheek is deeper than long, whereas in all other clupeoids it is at least as long as deep and usually longer than deep. In the herrings the lower jaw is bent sharply upward from its tip, forming a prominent angle midway of its length, while in the shad this character is much less pronounced, the line of the lower jaw being comparatively straight.

The female shad is larger than the male, the average difference in weight being more than a pound. The mature males taken in the fisheries of the Atlantic coast weigh from 1½ to 6 pounds, the average being about 3 pounds; the females usually weigh from 3 to 6 pounds, the average being about 4½ pounds. The general average for both sexes is between 3¾ and 4 pounds. In the early history of the fisheries shad weighing 11, 12, and even 14 pounds were reported, but 9-pound shad are now very rare on the Atlantic coast and 10 pounds seem to be the maximum. In some seasons an unusual number of large shad (7 to 9 pounds) appear in certain streams. On the Pacific coast shad average a pound or more heavier than on the Atlantic, occasionally attaining a weight of 14 pounds; many have been reported weighing 9 to 12 pounds.

RANGE AND ABUNDANCE

The natural range of the shad is the Atlantic coast of North America, from Florida to Newfoundland, its center of abundance being from North Carolina to Long Island, N. Y. In the early history of the country its numbers excited astonishment. Nearly every river on the Atlantic coast was invaded by immense schools, which in their upward migration furnished an ample supply of good food.

Remarkable success has attended the stocking of the waters of the Pacific coast with shad. In 1871, 12,000 shad fry from the Hudson

River were liberated in the Sacramento River by the California Fish Commission, and in 1873 the United States Fish Commission made a second deposit of 35,000. Subsequent plants in the Sacramento, aggregating 609,000, were made by the United States Fish Commission from 1876 to 1880. From these small colonies the shad have multiplied and distributed themselves along nearly 3,000 miles of the coast from southern California to southeastern Alaska. They reached Rogue River, Oreg., in 1882, and were taken in the Columbia as early as 1876 or 1877. About 1881 or 1882 they appeared on the coast of Washington, reaching Puget Sound in 1882. They were taken in the Fraser River, British Columbia, in 1891; in the Stikine River, near Wrangell Island, Alaska, the same year; and are now found along the entire coast from Los Angeles County, Calif., to Chilkat, Alaska, covering 22° of latitude. Their distribution from the standpoint of commercial importance is from Monterey Bay to the Columbia River.

On the northern part of the coast shad fry were first introduced in 1885, the number being 60,000. Of these, 50,000 were deposited in the Willamette River and 10,000 in the Snake River. The following year 850,000 were introduced into the Columbia River.

The first run of shad in California waters, after the young fry were liberated in 1871, appeared during the spring of 1877, and several thousand were sold in San Francisco. In 1886 it was estimated that 1,000,000 mature shad were taken from the waters of the State and sold in local markets. By 1912 shad had become so plentiful as to be almost a nuisance. In 1915, 33 carloads of fresh shad were shipped to eastern markets, and in addition to the number shipped it is estimated that the local markets absorbed 4,000,000 pounds, while 700,000 pounds of shad roe were sold fresh or put up in ½-pound cans.

Owing to heavy fishing, signs of depletion were already in evidence. The number of shad entering the Sacramento River in 1915 was estimated at 60 per cent of the run of the previous year, and the run in 1916 was estimated at 40 per cent of the run for 1915. This depletion was apparently due to extreme overfishing. The use of large meshed gill nets permitted the escape of large numbers of male fish but few females. In 1915 the males outnumbered the females 20 to 1 in the San Joaquin River, and in 1916 nearly 40 to 1. At the present time the annual catch of shad in California is considerably less than 1,500,000 pounds.

The shad is now one of the abundant fishes in the rivers of California. As a result of the liberation of the first two consignments adult shad were caught in 1874, and by 1876 this fish had become numerous. In 1880 specimens of all sizes were taken in the Sacramento River and Monterey Bay, and it was evident that the shad had begun to multiply, its increase up to 1883 being very great. On the west coast it is most numerous in San Francisco Bay and its tributaries, where, contrary to its habits in Atlantic waters, it is found throughout the year. In the Columbia it is regularly found as far upstream as the Cascades, about 150 miles above the mouth of the river.

The principal shad fisheries of California are in upper San Francisco Bay and in the delta regions of the Sacramento and San Joaquin Rivers. The vast delta basin of the San Joaquin has proved an ideal spawning place. Shad are taken occasionally in Monterey Bay, but these are utilized by the fresh markets, for they are here taken when they are not running in large numbers in the rivers. Shad ascend the Sacramento River for 300 miles or more. Here they are caught in bass or salmon nets. Because of the inconvenience of shipping from this district and because of the low prices prevailing, extensive fishing here is hardly warranted, and often after the fish are caught they are dumped overboard.

Large numbers of shad fry have been liberated in tributaries of the Gulf of Mexico, but without results. Between 1873 and 1892 several million fry were experimentally placed in Great Salt Lake, Utah Lake, and Bear Lake, Utah, and from 1884 to 1886, 3,000,000 fry were liberated in the Colorado River at Needles, Ariz., but these experiments were unsuccessful.

The history of the shad fisheries indicates that as early as 1880 there had been a marked decrease in the yield from nearly every river on the eastern coast. This was before the results of artificial propagation had any effect. Following is a summary of production for various years:

	Pounds
1880	19, 400, 000
1888	38, 100, 000
1896	50, 398, 860
1908	25, 941, 000
1918–1922	15, 138, 989

These figures indicate that in recent times the maximum yields were attained in the nineties, and that the catch has since declined below the level of 1880.

The abundance of the anadromous fishes is too easily overestimated. Crowding as they do at one particular season into the restricted watercourses of our coastal slopes, they become an easy prey to man's pursuit, and unless the greatest foresight and restraint is exercised in connection with the fisheries their numbers are likely to diminish rapidly and their complete extinction is perhaps a matter of only a few years. On the Atlantic coast the commercial fisheries are, in many instances, concentrated at or near the mouths of the rivers, this tending to prevent an adequate escapment to the spawning areas in rivers. The erection of dams entirely cuts off large spawning areas, and the destruction of spawn and fry by sewage and other trade and industrial wastes and the large amount of sediment carried by the rivers at flood stage have made heavy drains upon the natural abundance of the shad. In many streams of the Atlantic seaboard the shad have been destroyed entirely by these combined agencies; in the others the number of shad that reach their spawning areas has been so diminished that natural reproduction is becoming yearly less effective in keeping up the supply.

COMMERCIAL IMPORTANCE

The shad is one of the most palatable and popular of fishes. Its flesh is rich but not oily, and the roe is considered a great delicacy. Since the days of George Washington and John Marshall "planked shad" has been regarded as one of the most delicious of dishes for the table. In value, it is the most important fish of the rivers of the Atlantic coast and, next to the Pacific salmon, the most important anadromous species of North America. Among the fishes of economic value in the United States only the salmon and cod exceeded it in value for many years, and, considering all branches of the fishing industry, only the whale fishery and oyster fishery, in addition to those mentioned, were financially more important than that of the shad.

In 1908 the catch of shad of the Atlantic seaboard was approximately 25,941,000 pounds, representing a value of $2,091,500 to the fishermen. According to recent canvasses, the catch of shad by States, in pounds and value to the fishermen, was as follows:

Date and locality	Pounds	Value	Date and locality	Pounds	Value
New England, 1919:			South Atlantic, 1918:		
Maine	414, 455	$28, 393	North Carolina	1, 657, 036	$376, 696
Massachusetts	62, 337	4, 309	South Carolina	167, 462	29, 085
Connecticut	463, 203	86, 637	Georgia	100, 540	26, 960
			Florida	963, 606	135, 844
Total	939, 995	119, 339			
			Total	2, 888, 644	568, 585
Middle Atlantic, 1920–21:					
New York (1921)	115, 692	27, 128	Pacific, 1922:		
New Jersey	168, 637	44, 460	Washington	48, 039	769
Pennsylvania	18, 872	5, 834	Oregon	578, 003	11, 332
Delaware	86, 836	16, 312	California	1, 133, 270	55, 513
Maryland (1920)	1, 867, 196	355, 217			
Virginia	7, 293, 805	1, 145, 106	Total	1, 759, 312	67, 614
Total	9, 551, 038	1, 594, 057	Grand total	15, 138, 989	2, 349, 595

HABITS AND LIFE HISTORY

Notwithstanding the economic importance of the shad and the attention that has been devoted to its artificial propagation for so many years, there is an extreme paucity of explicit knowledge as to its habits and life history. The extent and direction of the migrations of anadromous fishes are factors of vital interest. How is the run in one river affected by the fishing operations in another, and in what degree does artificial propagation at one point yield returns of value in another? The question also arises as to the origin of the "sea shad" which are a feature of the local markets on the northeastern coast. Are they bred in the southern rivers or are they a distinct race?

SHAD IN THE OCEAN

The shad passes most of its existence at sea, and little is known of its habits and movements when out of the rivers. The ocean areas to which it resorts are unknown, and what its salt-water food consists of has not been determined. In the Gulf of Maine it is known to associate in large numbers with mackerel and herring during the months of June, September, and October, being most numerous in June. It has been taken at North Truro, Mass., in the fall, when the ocean temperature was from 43° to 49°; in the month of November it has been found on the west side of Sakonnet River, R. I.; in May and June it has been captured with mackerel a few miles northeast of Cape Cod Light. Some instances of capture indicate that under certain conditions the adults may remain in the fresh-water rivers a whole year. In November, 1890, 600 were taken in the Chesapeake

Bay. It has been found in the Potomac River occasionally, in limited numbers, in August and September, and even during the last week in December. Its movements are apparently largely controlled by the water temperature. It is believed that it seeks to occupy an area having a temperature of 60° or 70°, and that its migrations are determined by the shifting of this area.

SHAD IN THE RIVERS

The annual migration of the shad from the ocean to the rivers is for the sole purpose of reproduction. It ascends to suitable spawning grounds, which are invariably in fresh water, occupying several weeks in depositing and fertilizing its eggs in any given stream.

Its migrations from the sea are in quite a regular succession of time with relation to latitude. It first appears in the St. Johns River (Fla.) about November 15, the season of greatest abundance being February and March. In the Savannah River (Ga.) and the Edisto (S. C.) the run begins early in January and ends the last of March. In the North Carolina rivers these stages of the migration are a little later. In the Potomac River advance individuals appear late in February, but the fish is most numerous in April. In the Delaware River the maximum run occurs about May 1. It reaches the Hudson River the last of March, and is found in the Connecticut toward the end of April, is most abundant the last of May, and leaves the stream late in July. In the Kennebec and Androscoggin Rivers (Me.) it is first taken in April and has left by the middle of July. In the St. John River (New Brunswick) it appears about the middle of May, and in the Miramichi River (New Brunswick) late in May.

The main body of shad ascends the rivers when the temperature of the water is from 56° to 66°, the numbers diminishing when the temperature is over 66°. The movement of the shad up the rivers is not constant, but in waves, causing a rise and fall in the catch. Successive schools enter the Potomac from February to July, the males preceding the females. Of 61,000 shad comprising the first of the run received at Washington, D. C., from March 19 to 24, 1897, 90 per cent were males. Toward the close of the season males are extremely scarce.

The erection of impassable dams along the rivers and streams was probably the first thing to curtail the natural spawning grounds of these fish and to seriously check their natural increase.

As shad enter the rivers only for the purpose of spawning, the fisheries are necessarily prosecuted during the spawning season and often upon the favorite spawning grounds. The increase of population has created a larger demand for these fish, and an increased intensity in the fishing has resulted. The number of shad that reach fresh water has therefore been greatly curtailed by assiduous fishing with all kinds of contrivances in the estuaries and in the mouths and lower parts of rivers.

From spawning until their return to the rivers shad eggs and fry are preyed upon by other fish, so that the majority of the young do not survive their few months' sojourn in fresh water, and of those that leave the rivers each season a very small percentage reaches maturity to deposit its eggs and contribute to the perpetuation of the species. In the rivers striped bass, white perch, black bass, and other predacious fishes devour the young, and when they reach salt water sharks, horse mackeral, kingfish, etc., undoubtedly destroy many adults. It has been observed by North Carolina porpoise fishermen that as the shad swim close along the shore the porpoises follow and feed on them until they pass into fresh water. In the rivers the adult shad is comparatively free from enemies.

FOOD

After entering the rivers the shad takes but little, if any, food previous to spawning but after casting its eggs it bites at flies or any small shining object and has been known to take the artificial fly. The mouth of the adult is practically toothless, and its throat contains no functionally active teeth. The water that passes through the branchial filter—the gill rakers—is deprived of the small animals that are too large to pass through its meshes. It is a common remark with fisherman and others that food is rarely found in the stomach of the adult shad in fresh water, but examinations have shown that the shad does, in some instances, eat small Crustacea, insects, etc. The only substance commonly found in its stomach in fresh water has the appearance of black mud. It is held by some that the shad swims with its mouth open and may unintentionally swallow the small organisms found in its stomach under such circumstances, but as far as observation of fish in aquaria and experiences of net fishermen go the shad does not swim with its mouth open.

SPAWNING

Shad in spawning condition may be found anywhere above brackish water, and under favorable temperature conditions spawn whereever they happen to be, but in some river basins they exhibit a well-defined choice of spawning places, preferring localities below the mouths of creeks, where the warmer water of creeks mingles with the colder channel water. The shad lays its eggs during the highest daily average temperature, a condition realized about sunset, when the warmer shoal water commingles with the colder channel water, establishing a balance. The principal spawning occurs from 5 to 10 p. m. Observations on the Potomac River show that of the eggs from shad caught in a seine only 11 per cent were taken between midnight and noon, the percentage in the morning being 14 one year and 8 another.

The eggs in the ovaries remain in a compact mass until they ripen, at first occupying but a small space but gradually increasing until they distend the whole abdomen, the average weight of the ovaries being about 13 ounces. Close examination at the approach of the spawning time will disclose large maturing eggs of rather uniform size and others smaller and of variable size. Whether the latter are the forming eggs for the next year, for two or three succeeding years, or for the lifetime of the fish, has not been determined, nor is it known whether shad spawn every year. The small and shrunken ovaries of a spent fish are found still full of these eggs of different sizes. Shortly before spawning, transparent eggs of large size, contrasting strongly with the opaque golden hue of less mature ones, will be found scattered through the still compact ovarian mass, gradually becoming more and more numerous. The mature eggs are finally freed from the remainder of the ovary and extrusion begins, a liquid stream of eggs and mucus flowing from the oviduct on the slightest pressure of the abdomen.

Freshly deposited shad eggs are of a pale amber or pink color, and are transparent. They are about $\frac{1}{14}$ inch in diameter and somewhat flattened and irregularly rounded in form. The egg membrane is much wrinkled and lies in close contact with the contained vitellus. Immediately after fertilization the egg becomes spherical through the absorption of water and apparently gains very much in bulk, measuring about $^1/_7$ of an inch in diameter; but this gain is only the distended egg membrane, the vitellus or true germinal and nutritive portion not having increased. The vitellus is heavier than water, and a large space filled with fluid now exists between it and the membrane, the vitellus rolling about and changing its position as the position of the egg membrane is altered. No adhesive material is found on the outside of the membrane, though when first extruded the eggs are covered with a somewhat sticky ovarian mucus.

In a state of nature the shad deposits its eggs loosely in the rivers without building a nest, the two sexes running along together from the channel toward the shore and the eggs and milt being ejected simultaneously. On quiet evenings, at the height of the season, spawning shad may be heard surging and plunging along the shores. By fishermen this is termed "washing."

Shad are prolific, but much less so than many other food fishes. The quantities of eggs taken by spawn takers do not represent the actual fecundity, for many are cast in advance of stripping. The average number is not more than 30,000. Single fish have been known to yield 60,000, 80,000, 100,000, and 115,000 eggs, and on the Delaware River, in 1885, one yielded 156,000. Many eggs fail to be fertilized, and but a comparatively small percentage of those impregnated are hatched. After being extruded the eggs sink to the bottom, where they remain until hatched subject to the attacks of fish and other water animals. Eels are very destructive to shad spawn and often attack shad caught in gill nets, devouring the undeposited eggs and sometimes mutilating half the catch of a gill-net fisherman.

The development of fungus is one of the greatest dangers to shad eggs in a natural state, and another potent agency for their destruction is the mud brought down by heavy rains, burying and suffocating the eggs.

After spawning, shad are denominated "down-runners," "racers," and "spent fish." They are then very lean and hardly fit for food, but they soon begin to feed and have become fatter by the time they reach salt water in the summer or fall.

YOUNG SHAD

In the Middle Atlantic States the young fish remain in the rivers until the cool weather of fall comes; then they begin to drop downstream, and by the last of November have passed out into the oceans or bays and are lost sight of until they come back, 3 or 4 years later, full-grown and ready to spawn. They leave the Potomac River when the water falls to about 40°, by which time they are about 3 inches long. They have been observed in great abundance about

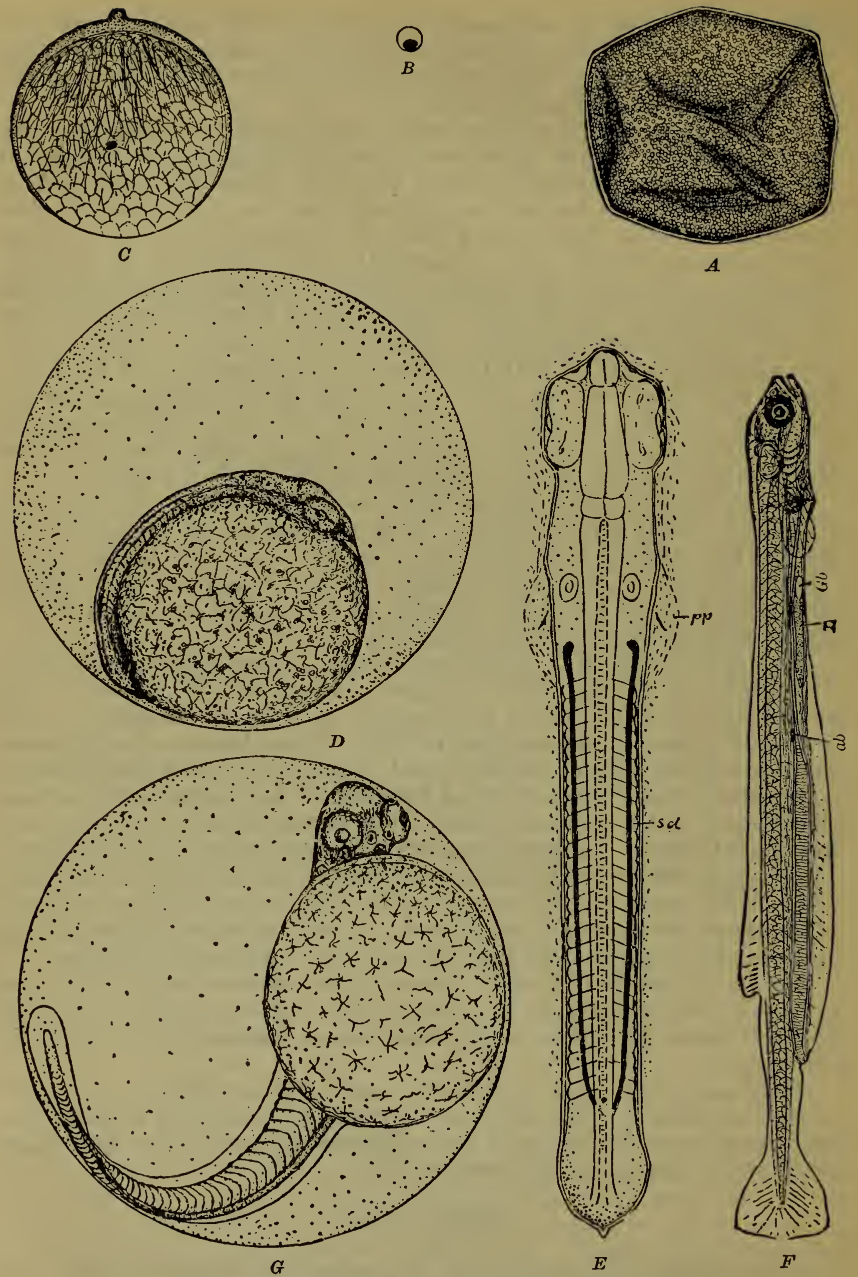

FIG. 2.—Egg and larval stages of the shad (*Alosa sapidissima*)

A. Freshly extruded egg enlarged, showing its envelope much wrinkled.
B. Shad egg, showing vitellus and distended egg membrane, natural size.
C. Shows the gradual accumulation of germinal matter at one pole of egg, the polar prominence externally, and presence of plasmic processes extending down through the vitellus.
D. Embryo shad in its natural position in its spacious enveloping membrane. From a photograph.
E. Diagrammatic representation of an embryo to show course of segmental ducts *sd* and extension outward of pectoral plates *pp*, which are intimately concerned in the development of pectoral fins.
F. Side view of a young shad 13 days old, viewed as a transparent object. *ab*, rudimentary air bladder; *L*, liver; *Gb*, gall bladder.
G. An embryo in its envelope, on the third day of development, nearly ready to hatch.

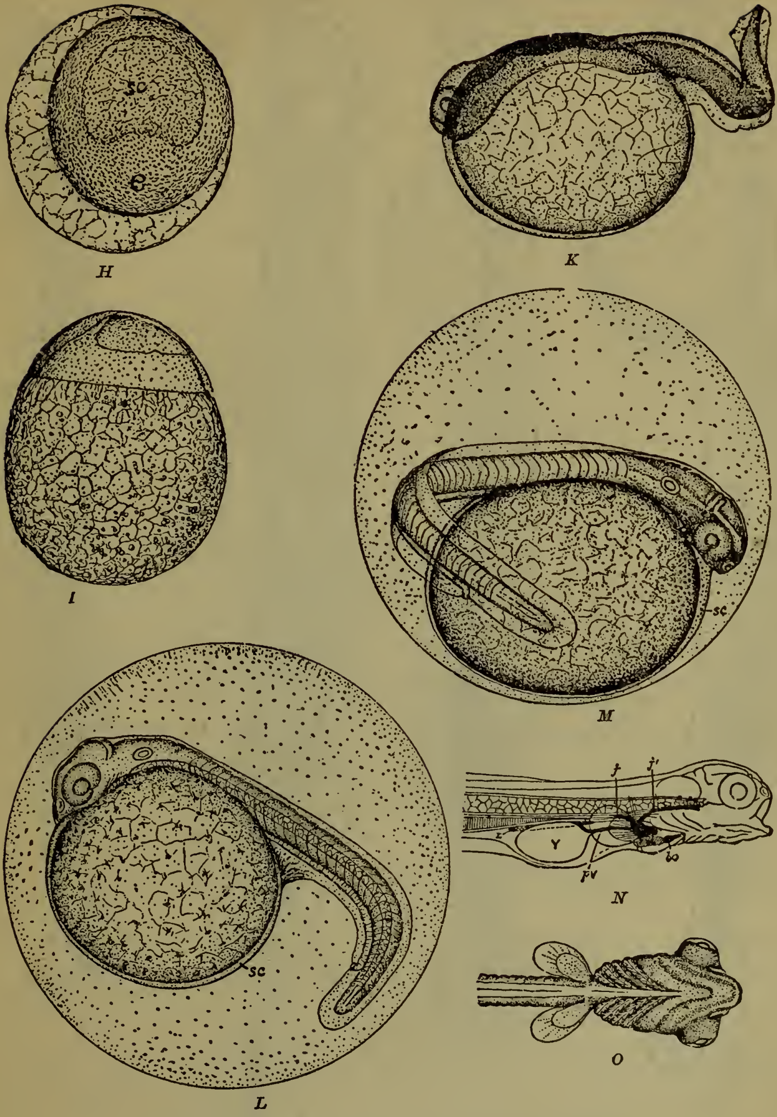

FIG. 3.—Egg and larval stages of the shad (*Alosa sapidissima*)

H and *I*. Two views of an egg after the blastoderm has spread considerably and the embryonic area *e* is well defined.

K. View of unhatched embryo, which developed in a temperature of 45° F., producing distortions of tail.

L. An egg envelope with its contained embryo, 44 hours after impregnation, viewed as a transparent object.

M. An egg envelope with its contained embryo at the beginning of the third day of development. From a photograph.

N. Anterior portion of a young fish on fourth day. To show relations of liver *L* to yoke *Y*, over which the portal vessel *pv* passes forward to empty into the venous sinus, in common with the anterior and posterior jugulars *j'* and *j*, *ba* bulbus aortae, *ve* ventricle.

O. View of fore part of a young fish 17 days old, from ventral side.

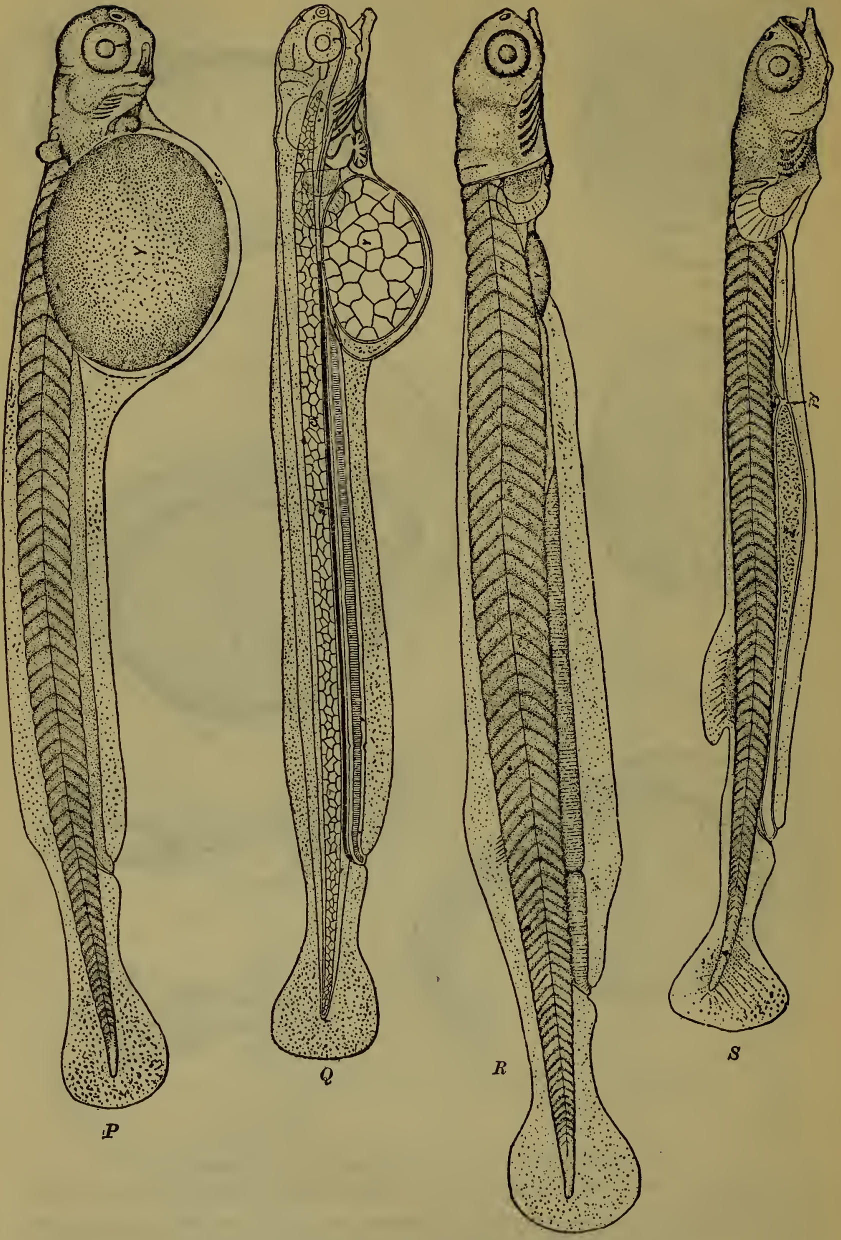

FIG. 4.—Larval stages of the shad (*Alosa sapidissima*)

P. Young fish immediately after hatching, viewed as an opaque object and somewhat obliquely from one side, to display the relations of branchial and hyomandibular arches, and position of pectoral fin.
Q. Young fish third day after hatching, viewed as a transparent object to show extention of segmental duct forward; chorda *ch*.
R. Young fish 5 days after hatching, very much enlarged, and viewed as an opaque object. Only a slight remnant of the yolk sac *Y* remains.
S. Young fish 17 days after hatching, viewed partly as an opaque and partly as a transparent object; *py*, pylorus and rudimentary air bladder above it; *I*, intestine, filled with the remains of ingested food. The opercula are already so far developed as partly to conceal the gills.

Bryans Point, on the Potomac River, feeding and jumping out of the water about sunset. They keep within the open streak of water between the shores and the aquatic vegetation that covers the flats, in water 2 to 5 feet deep. After mild winters young shad have been found in the Potomac River in April, 30 miles above brackish water and 160 miles from the ocean, in company with young alewives. Some immature shad, apparently 2 years old, are caught each year in seines operated in the fresh water of the Potomac River, and undersized shad are frequently caught in the New England rivers, where tidal waters extend only a short distance.

EARLY ATTEMPTS AT SHAD CULTURE

The systematic development and extension of shad culture were undertaken with the definite purpose of testing the value of artificial propagation in maintaining an important fishery which was being rapidly depleted. As early as 1848 shad eggs were artificially taken and fertilized, and in 1867 more extensive experiments were made on the Connecticut River, and later on the Potomac, with encouraging results. The attention of many States was thus attracted to the work, and in 1872 it was taken up by the General Government. Prior to the experiments on the Connecticut, certain species of the salmon family had been principally dealt with in fish-culture, and different methods from those in use were necessary for shad hatching, owing to the less specific gravity of shad ova and the much shorter period of time required for the development of the fish from the egg.

The "Seth Green box," a modification of the floating box used for hatching trout and salmon eggs, was first tried with great success, but floating boxes were subject to various accidents when used in tidal waters, and in rapid succession devices of various kinds were brought forward to supplant them. The most important were hatching cones and the plunger buckets, which, though imperfect, rendered more extended operations possible.

At that time the apparatus was arranged on flat-bottomed barges or scows, which were towed from point to point along the coast from Albemarle Sound to the Susquehanna River.

The Chase jar, used extensively in the propagation of whitefish, was also tried, but the McDonald universal hatching jar was finally adopted as standard equipment for shad hatching in 1882 and is still in use. The "universal" jar has given excellent results and is still a prime favorite with numbers of fish-culturists, who claim that it has advantages (particularly in removing dead eggs or any foreign matter that may inadvertently become mixed with the eggs) not possessed by any other type. In view of the excellent results obtained from the use of the Chase and other types of open-top jars, their greater simplicity in operation, absence of complicated parts and fittings, and their lower cost, it is doubtful that the "universal" jar possesses advantages over the other types that would warrant its installation in equipping a new hatchery.

During the years of experimental work, from 1872 to 1880, 97,471,700 shad fry were planted, beginning with 859,000 in 1872, while in 1880, 28,626,000 were distributed. Prior to 1880 deposits of a few hundred thousand each were made in as many different streams as possible, but the increased production of young fish made it possible to ship and plant the fry by the carload, and by 1884 shad culture was established on a large scale, barge operations were abandoned, and the work conducted on shore. The basins of the Chesapeake Bay and Delaware River had meanwhile been selected by the United States commission as the natural seat of operations, though the State commisions from Massachusetts to South Carolina were actively engaged on their own account. At the present time Maryland and Connecticut are the only States actively engaged in shad culture.

Every river on the Atlantic coast from Massachusetts southward has been examined by the agents of some State commission or the United States, or by both, in order to determine the natural spawning grounds of the shad. On nearly every stream hatcheries have been operated at one time or another, but usually eggs were not obtained in sufficient numbers to justify continued operations.

In certain river stretches, apparently favorable, no ripe fish were found; for example, in the Roanoke River for 15 miles above its mouth, where 10,000 to 15,000 shad were taken annually, mature eggs were not found, though the fish were spawning just below there, as they did many miles above at Weldon. In the Sutton Beach seine, the one in North Carolina waters that had afforded the most spawn, only about one spawning shad to each 100 was caught, and the annual catch of this seine was 30,000 to 75,000 per annum. In view of such facts, it is not remarkable that difficulty has been experienced and time consumed in deciding on permanent locations for hatcheries.

The spawning period varies widely in different seasons; in some years shad are numerous and in spawning condition two or three weeks after the time when they have ordinarily disappeared. They deposit eggs at some point along the coast for six continuous months.

The following streams have been occupied by hatcheries, as two of them are now, and it will be observed that the approximate spawning periods, beginning early in the South, become gradually later toward the North.

Waters	Place	Period
Edisto River	Jacksonboro, S. C	Mar 5 to 26.
Albemarle Sound	Avoca, N. C	Apr. 1 to 30.
Potomac River	Below Washington, D. C	Apr. 15 to June 10.
Susquehanna River	Below Havre de Grace, Md	Apr. 17 to June 15.
Delaware River	Gloucester, N. J	May 10 to June 20.
Hudson River	Below Albany, N. Y	May 15 to June 30.
Housatonic River	Birmingham, Conn	Do.
Connecticut River	Holyoke, Mass	June 15 to July 5.
Merrimac River	North Andover, Mass	June 1 to July 15.

The more important points at which the Bureau of Fisheries has conducted shad-cultural operations in the past are at Battery Island, near the mouth of the Susquehanna River, and at various points on the Delaware River, principally at Gloucester N. J.

SUSQUEHANNA RIVER

The shoal water in the neighborhood of Battery Island was an extensive and valuable spawning ground. The station was conveniently located on the island and the possibilities for egg collecting appeared to be almost unlimited. Hundreds of gill-net fishermen were engaged, and large seines were operated within easy distance. As early as 1886 the egg collections exceeded the capacity of the hatchery and numbers were diverted to other points. In 1888 over 105,000,000 were taken, and in 1898 the egg collections totaled 209,992,000. Both egg collecting and hatching were carried on, and the establishment was complete in itself. Work at this point was first undertaken in 1877, and in 1880 a permanent station was established, which was continued in operation during each shad season up to and including the season of 1916.

DELAWARE RIVER

The steamer *Fish Hawk* was employed in shad hatching on this river nearly every season from 1887 to 1910, the egg collecting and other labor being performed by the crew. An interesting feature of the work was the large yield of eggs per fish. Eggs from this river were saved regularly from seines, but the available product among the gill-net fisherman was never fully ascertained. The eggs collected by the *Fish Hawk* numbered 51,983,000 in 1899.

The abandonment of the work at both of these places was brought about by the conditions already mentioned. At the present time two stations are maintained for shad culture—on the Potomac River at Bryans Point, Md., and on Albemarle Sound, N. C.

POTOMAC RIVER

The Potomac River immediately adjacent to Fort Washington (12 miles below Washington, D. C.) was and continues to be more productive of ripe shad eggs than any other place of equal area. This was discovered as early as 1880, and a station was soon developed there with full equipment. In March, 1892, the station was moved to its present location at Bryans Point, on the Maryland side of the river opposite Mount Vernon.

As shown in the following table, there has been considerable fluctuation in the numbers of eggs that have been available for artificial propagation each year at the Potomac River hatchery since the inception of the work at that point.

Year	Number of eggs taken	Year	Number of eggs taken
1880	20,749,000	1902	45,971,000
1881	43,200,000	1903	86,370,000
1882	21,800,000	1904	34,636,000
1883	24,274,000	1905	23,649,000
1884	19,000,000	1906	12,695,000
1885	22,576,000	1907	39,278,000
1886	36,362,000	1908	30,559,000
1887	59,435,000	1909	13,080,000
1888	81,177,000	1910	34,796,000
1889	58,233,000	1911	30,526,000
1890	35,202,000	1912	88,727,000
1891	32,980,000	1913	30,913,000
1892	13,446,000	1914	29,808,000
1893	9,423,000	1915	16.012,000
1894	32,393,000	1916	63,815,000
1895	66,065,000	1917	77,580,000
1896	64,788,000	1918	40,231,000
1897	39,707,000	1919	50,487,000
1898	68,724,000	1920	42,570,000
1899	49,283,000	1921	15,620,000
1900	67,904,000	1922	47,478,000
1901	33,321,000	1923	17,627,000

It appears to be the concensus of opinion that abnormally high or low temperatures affect the runs of fish. If the temperatures are high, the fish tend to leave the main channels and scatter over the shallow-water areas of the bay, where they are more easily taken by the traps, thus reducing the numbers that ultimately reach the spawning areas. If the temperatures are low, the fish tend to follow the deeper channels, and thus a larger number reach the spawning areas and the take of eggs is correspondingly larger.

Egg collections at other points where artificial propagation has been undertaken gradually dropped from large numbers (200,000,000 representing the full capacity of the hatchery for several seasons on the Susquehanna River) to a point where hatchery operations were no longer practicable. The causes effecting this condition are, of course, more or less conjectural, but it is noteworthy that the shad fishery of the Potomac River has had, in addition to the benefits of artifical propagation, some protection from the excessive fishing to which other areas have been subjected, by the enforcement of the regulatory measures of the War Department maintaining lanes unobstructed by fishing apparatus for purposes of navigation.

ALBEMARLE SOUND

The hatchery on Albemarle Sound was permanently located in 1900 near the town of Edenton, adjacent to what was one of the most important shad-fishing grounds in the country. This region for a number of years yielded annually upward of 8,500,000 pounds of shad, valued at about $350,000, and contributed the principal part of the shad of the northern and eastern markets in winter and early spring. The egg collections at this station are indicated in the following table:

Year	Number of eggs taken	Year	Number of eggs taken
1881	5,727,000	1911	74,630,000
1897	27,901,000	1912	115,617,000
1898	12,334,000	1913	138,912,000
1899	21,267,000	1914	42,885,000
1900	10,404,000	1915	39,040,000
1901	75,400,000	1916	16,060,000
1902	37,987,000	1917	7,625,000
1903	36,320,000	1918	4,223,000
1904	10.276,000	1919	31,323,000
1905	6,748,000	1920	21,667,000
1906	25,643,000	1921	21,710,000
1907	23,644,000	1922	35,201,000
1908	55,866,000	1923	17,877,000
1909	59,685,000	1924	16,452,000
1910	69,233,000		

PACIFIC COAST

With the appearance of the shad as an important feature of the commercial fisheries of the Pacific coast, the desirability of artificial propagation was recognized, and as early as 1906 shad culture was undertaken at points on the Willamette River, Oreg. The work was continued on this river, principally at Willamette Falls and St. Helens, Oreg., until the summer of 1920. It was discontinued at that time because, by action of the proper State authorities, fishing was prohibited entirely on the principal spawning areas of the river. The spawning season in this river extends from late May to early June.

ARTIFICIAL PROPAGATION

In the Potomac River, where it is still possible to conduct shad-cultural operations successfully, the average annual catch for the five-year period, 1919 to 1923, was 543,000 fish. The average take of eggs for this period was 34,756,400 per annum. The egg take on the spawning areas in proportion to the catch of fish in the entire river was 64,000,000 eggs per 100,000 fish. At the present time, under existing conditions on the Potomac River, a maximum egg take is secured. Assuming that similar conditions would obtain in other streams, it is obvious that there are very few streams on the Atlantic coast with a sufficiently large run of shad to warrant the establishment of propagating stations; in such streams the rehabilitation of the fishery must be secured by other means. To this end it is desirable that the shad be unmolested on the spawning areas, that a proper escapement be provided for, and that the commercial fishermen strip the ripe fish caught in their nets, fertilize the eggs, and return them to the water to develop under natural conditions.

The methods hereafter described are those in use at the Bryans Point (Md.) hatchery, though they do not differ in any material way from those employed elsewhere.

EGG COLLECTING

For a number of years it was the custom to employ spawn takers to visit the seines or gill nets employed in the commercial fishery for the purpose of obtaining any mature eggs that might be available in the catch of shad. In recent years, with the advent of the motor boat and the more general use of gill nets, the fishery is no longer concentrated but is extended over a much wider area than formerly. Under these conditions the employment of a sufficient number to cover the work is impracticable and the method has been entirely abandoned on the Potomac River, though it is still followed to some extent in the work on Albemarle Sound, N. C.

On the Potomac River the commercial fishermen take shad eggs for artificial propagation, fertilize them, and deliver them on the fishing grounds or to collecting boats sent out for the purpose. In advance of the spawning season all fishermen operating within a reasonable distance of the hatchery are provided with pans, dippers, and other necessary equipment to take and care for the eggs, and each day's collection is promptly delivered by the fishermen. After the eggs have been in the hatchery for 48 hours (at the expiration of which time mortality has practically ceased) all good eggs remaining are carefully measured, and each fisherman receives compensation at the rate of $22.50 per million eggs, the measurement being based on 28,000 eggs to a fluid quart.

DIFFICULTIES ENCOUNTERED IN COLLECTING EGGS

A peculiar characteristic of the shad is that fish in prime spawning condition are rarely taken by any form of fishing appliance except between the hours of 4 and 10 o'clock p. m. Eggs in fish taken during the morning hours seldom are sufficiently advanced to respond to artificial treatment, and fish taken after 10 p. m. are usually spent or partially so.

As a rule, the best eggs are secured from the gill nets. Eggs from fish taken in the large seines usually are of an inferior quality, but those from the smaller seins, which are landed very soon after the fish have been surrounded, are of a better grade. The eggs from fish held in pound nets for several hours are valueless for artificial propagation, since shad die very soon after capture and the eggs rarely are susceptible of fertilization longer than 20 minutes after the fish have been taken from the water. This peculiarity is, perhaps, one of the most deterrent factors against large egg collections.

Gill nets are most effective at night and are customarily lifted during the last stages of the ebb tide and the beginning of the flood. Therefore, while other conditions may be favorable, but few eggs are obtained unless the proper stage of the tide coincides with the spawning hours of the fish, since at other times they are not in good condition for stripping.

A scarcity of male fish toward the end of the season often cuts short operations when eggs are plentiful. Unsuccessful attempts have been made to capture the males at such times by using gill nets having a mesh smaller than that in the nets used by the market fishermen. Attempts have been made, also, to pen the adults, but without success, as the fish become diseased and their eggs spoil within them.

CLIMATIC CONDITIONS AND EGG COLLECTIONS

During their migration up the rivers to the spawning grounds shad are very responsive to climatic conditions. During a very warm season the fish attain spawning condition earlier than under normal conditions, while an unusually cold season will have the opposite effect. A water temperature of 80° has been known to result fatally to shad eggs, not only to those under incubation but also to the eggs in the parent fish. The same effect will be produced by an abnormally low water temperature or sudden fluctuation in either direction.

Early in March the mean water temperature of the Potomac River at Bryans Point, Md., is normally between 36° and 40°; by the middle of April, when the spawning season usually opens, it is between 52° and 58°; and by the close of the spawning period, at the end of May, the average is from 65° to 70°. Freshets, unusual turbidity of water, and the direction and velocity of the wind all are influential factors in the movements of shad.

STRIPPING AND FERTILIZING THE EGGS

In stripping the eggs the shad is lifted with the right hand and caught above the tail with the left. All slime and loose scales are removed by going over the fish two or three times in quick succession with the right hand. The head is carried to the left side under the arm and there retained by the arm, the tail being bent slightly upward with the left hand. When the fish is properly adjusted, its head is nearly concealed. The fish is held firmly over a moist pan, and with a moderate downward pressure of the right hand the eggs will flow freely if mature. Two fish may be stripped into each pan. Even with the utmost care it is impossible to preserve the life of the fish during the stripping process. When taken from the water, the shad is a very muscular fish, and if not firmly held while obtaining the eggs it is very likely to slip from the operator's grasp and flounder into the pan of eggs, probably throwing a large portion of them out and causing damage to those that remain.

The first half teaspoonful of eggs should be pressed out into the palm of the left hand and inspected. Skilled operatives usually discern ripeness by general outward appearance. A slow but almost positive test consists in running some of the eggs into water, when, if dead, they will have the appearance of boiled rice. Bad eggs are sometimes beyond the detection of the most skilled fish-culturists, however. If the eggs are white, opaque, or of milky appearance, the fish is put aside. Immature eggs are white, small, and adhering in clots, or they may be transparent and yet unyielding to pressure.

The former are valueless, while the latter can sometimes be utilized by putting the fish aside to soften. Both ripe and green eggs sometimes occur in the same fish, but only expert operatives can hope to take the one and leave the other. If eggs are mature, but little pressure is necessary to start them; and if not, they are only injured by squeezing, and will either not flow at all or will come away with difficulty in clotted masses and generally with a little blood.

To obtain the milt, the spawn taker catches the fish by the back, taking hold of the underside with the right hand. Without relaxing pressure at any point the milt is forced out with the thumb and forefinger. Good milt is so thin that it flows in a steady stream, and from some fish it can be ejected widely over the surface of the eggs, but in fish that have been dead some minutes the milt is lumpy and flows only in drops. After the milt has been applied, from half a pint to a pint of water from the river is added and the pan given a slow rotary motion, continued until the milt is thoroughly mixed, when the water will have a milky appearance.

Shad eggs have not the same strong adhesive tendency displayed by eggs of most of the Salmonidæ immediately after fertilization. Nevertheless, the adhesive tendency is apparent, and it is important that the eggs and milt be thoroughly mixed by movement of the pan as described above; otherwise a large portion of the eggs comprising the lower strata in the pan will not expand with the absorption of water and will fail entirely of fertilization.

In one minute after thorough mixing the milt may be washed off with safety, but usually several pans are to be looked after, when the milt may be allowed to remain 5, 10, or even 15 minutes. After the last pan of eggs has been fertilized they are rinsed, beginning with those first taken, by pouring in a quart of water. The stream of water should be directed between the eggs and the sides of the pan, as the eggs may be injured if the water is poured directly upon them. Then the pan is tipped, the water being drained over the edge slowly. The operation should be repeated, and the third time the water should be left upon the eggs. The eggs must be well stirred with the inflowing water.

There need be no fear of applying too much milt. The amount obtained from one fish may be ample for the eggs from two, but it is always better to employ two males. Eggs may look promising for two or three hours, yet never expand to full size or produce fish. They lie at the bottom underneath any good ones that may be in the pan; they stick to the fingers, while the good ones will not, nor can they be successfully removed from hatching jars until after several days. Unskilled spawn takers are liable to the mistake of stripping eggs without having the necessary milt to impregnate them, for several spawners may be taken over a period of 10 or 20 minutes without the capture of a male fish. In such cases (of great frequency late in the season) the female fish must be placed conveniently, backs down, to prevent the eggs from running out, and the males may have to be obtained from other boats. When ripe shad are taken in seines two or three large baskets should be in readiness to receive them.

Good eggs are transparent and so soft and light that they are not apparent to the touch when the fingers are moved among them. When the temperature is about 70° no change is observed for about 12 or 13 minutes after the milt is added, but about this time a careful movement of the fingers in the pan discloses their presence, and in a little more than 20 minutes from the time the milt is applied they feel like shot against the fingers and to an experienced eye are observed to increase slightly in size; when a day old they will not break if dropped to the floor. In transferring the eggs to other vessels the rim of the smaller pan should be gently immersed beneath the water surface in the larger one and the pouring take place gradually. To prevent splashing in boats, a small pan should be put on the water surface of the larger pan. Sudden jars must be avoided, all foreign substances excluded, and the pans be free from grease and salt. After the application of milt they expand to full size in 20 to 60 minutes, depending partly on temperature, and at this stage they may be doubled up in the larger pans, the question of safety in moving them being determined by their hardness.

If the eggs have absorbed sufficient water in the spawn pan, they swell and adhere to each other, forming a compact mass, and are ready to be transferred to the hatching jars, but if they are not sufficiently expanded or "water-hardened" they must remain in the pans, from 30 to 60 minutes being required for their full expansion.

In transferring the eggs to the hatching jars a small screen is placed over the throat of the egg funnel mentioned on page 482, which serves to remove any fish scales or other foreign matter that may have become mixed with the eggs.

HATCHERY AND EQUIPMENT

The building intended solely for a shad hatchery need not be of elaborate construction, since it will be used for only a short period of time during the year, but ample space, light, ventilation, and arrangements for moderate heating are essential. At the Bryans Point hatchery the water supply is obtained from the Potomac River, being delivered through steam pumps to elevated tanks, from which it is distributed to the hatchery. During periods when only a small number of eggs are in the hatchery a sufficient amount of water is supplied through a pump operated by a gasoline engine. This pump has a 4-inch suction and is connected with the main suction line by the use of a tee joint. The suction pipe, of 6-inch galvanized iron, is carried into the river on a pier approximately 170 feet long. The end of the pipe is held some distance from the river bottom and is provided with a protecting screen. At this station the tanks are elevated to a sufficient height to provide a pressure of 8 pounds per square inch at the top of the hatching jars, and each jar requires approximately 3 quarts of water per minute for its successful operation.

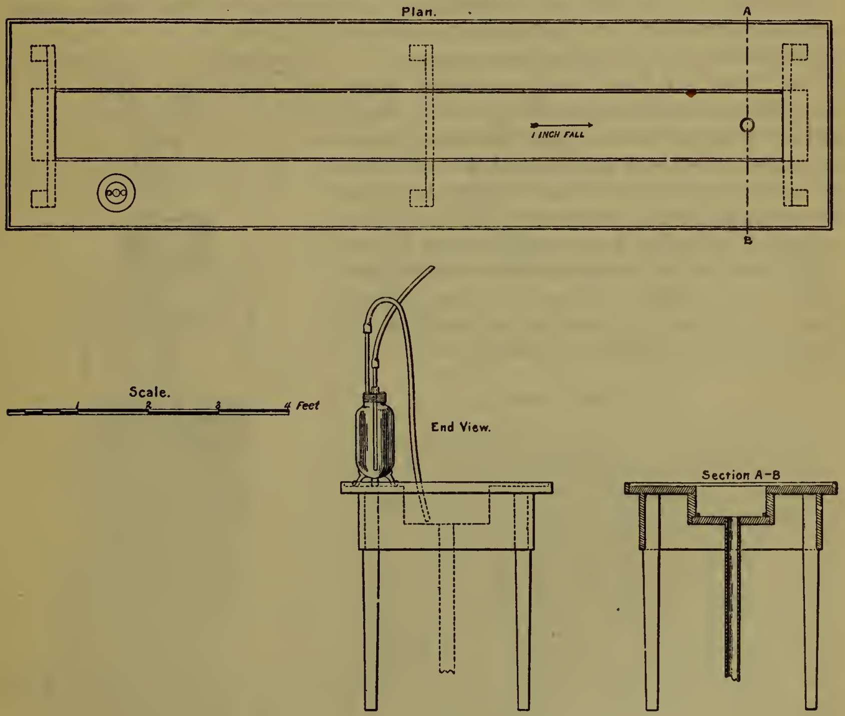

FIG. 5 Shad-hatching table

Upper figure shows view from above.
Lower left-hand figure is an end view showing hatching jar in position.
Lower right-hand figure shows a cross-section of the drain pipe and trough in center of table.

In exceptional cases water may be obtained from a municipal water supply, but as such water is frequently sterilized with chlorine or other agents, and as these sterilizing agents have been found, even in very dilute solution, to have a decided toxic effect on the ova, embryos, and young of many fish, such a source of water supply for hatching purposes must be viewed with suspicion.

The hatching jars are arranged on tables, as shown in Figure 5. The tables usually are 16 feet long by 3 feet wide and of an appropriate height for convenience in the manipulation of the jars. A table of the dimensions given will accommodate 24 jars in a double row—12 on each side of the rectangular tanks placed in the low center section of the table to receive the fry—and into which the discharge water from each jar enters. The fry tanks in general use are of glass, though wooden tanks are entirely satisfactory. A 1½-inch iron pipe, connected with the main water supply, is extended lengthwise over the center of each table. In this pipe, on either side, are inserted ¼-inch brass pet cocks, one for each jar, from which water is supplied to the jars through ½-inch rubber tubing. The overflow from the fry tanks is taken care of by a standpipe, 1¼ inches in diameter, running through the bottom of the tank and secured by a lock nut. Inside the tank the pipe is entirely surrounded by a frame, either square or circular, covered with wire gauze, which excludes the fry from the overflow. At one end of the table a pipe of suitable size is fastened to convey waste water to the drainage system.

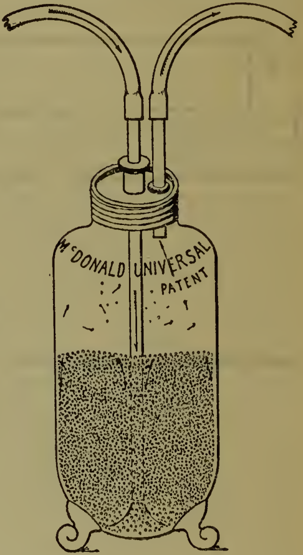

FIG. 6.—McDonald automatic hatching jar

In view of the comparatively short incubation period of shad eggs and certain other considerations, shad-hatching operations have been conducted on the type of table herein described. Should it become expedient, because of an increased number of eggs, to curtail space in the hatchery or to conserve the water supply, the simpler forms of the "single battery" used in pike-perch work could be used successfully for shad.

HATCHING JARS

Very early in the development of its fish-cultural activities the Bureau of Fisheries was confronted with the necessity of dealing with the eggs of shad, whitefish, and other species in immense numbers. If the work was to be of practical value, eggs by the hundreds of millions, not by thousands, must be handled. After successive experiments the McDonald automatic hatching jar was devised, and it is still in favor with many fish-culturists. The Chase and Downing jars, which are also in general use, are simplified modifications of the McDonald jar.

Perhaps the most meritorious feature of these jars is that they prevent the development of the saprolegnious fungus, which caused so great a mortality in some other forms of hatching contrivances in which all the ova were not in continual movement. The very gradual, gentle, and continual rolling movement of the ova upon each other in the jars apparently prevents the spores of the fungus from adhering. The cleanliness of the apparatus is also advantageous, and as the material of which they are made is glass the progress of development can be watched satisfactorily from the outside of the jars.

McDonald jar.—This jar (fig. 6) is a cylindrical glass vessel of about 7 quarts capacity, with hemispherical bottom, supported upon three glass legs. The top is made with threads to receive a screw cap. It is closed by a metallic disk, perforated with two holes ⅝ inch in diameter—one in the center admits the glass tube that introduces the water into the jar, the other, equally distant from the central hole and the edge of the metal plate, admits the glass tube that carries off the waste water. The central tube is connected by ½-inch rubber tubing with the petcock, which regulates the supply of water. A groove in the inner surface of the metallic plate carries a rubber collar, and when the plate is in place the tightening of the metallic screw cap seals the opening hermetically. Both the inlet and outlet tubes pass through stuffing boxes provided with gum washers and binding screws. The central or feed tube is provided with stuffing boxes, one on the top of the disk and one on the bottom, the better to hold it to a true center. The outlet tube is provided with only one stuffing box, and the binding ring is beveled.

This type of jar works very satisfactorily with shad or other semi-buoyant eggs. The outlet tube may easily be shoved down into the jar, so that the dead eggs may be siphoned off. Its first cost is about twice that of the open-top jars. The open-top jars may be arranged in batteries or tiers, thus giving greater hatching and incubating efficiency for the same floor space. The open-top jars are easier to set in place, and the breakage is also less. The contour of the bottom of the McDonald jar causes the dead eggs to separate from the good eggs very readily.

Chase jar.—The Chase jar is similar to the McDonald type in egg capacity. In shape it differs at the bottom, being more pointed and having a solid base (fig. 7). The main point of difference is at the top, which, in the Chase jar, tapers in slightly from its greatest diameter near the bottom. The top is open and is fitted with a metal band, from which extends a spout about 3 inches long, 2 inches wdie, and ¾ inch deep. In operation the jar is placed in such a position that the spout will discharge directly into the fry tanks, thus delivering the overflow water with the fry directly into the tank. Its egg capacity is equal to that of the McDonald jar.

All open-top jars cost less to purchase than the closed-top type. The open jars require slightly more water to operate them successfully. The contour of the bottom of the Chase jar is such that the eggs readily segregate, the dead ones rising to the top, where they may be removed.

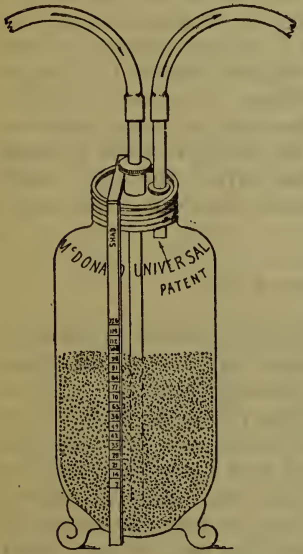

FIG. 7,—Application of a measuring scale to a jar of shad eggs

The other types of open-top jar, including the Downing jar, are similar to the Chase jar, with the exception of the metal band and spout, which are not used, the glass being molded to form the overflow channel. Another point of difference in jars of the McDonald and Chase types is the contour of the bottom, which is so shaped as to permit of an even regular motion of the eggs through the action of the inflowing water. In the other types of open-top jars the shape of the bottom is more pointed, making it extremely difficult to obtain a uniform motion, so desirable and essential in the successful incubation of shad or similar eggs.

SELF-CENTERING TUBE

In place of the glass tube held rigidly in position by the fittings in the closed top of the McDonald jar, through which water is supplied, a metal tube (fig. 8) is substituted in the open-top jars. This tube, which is usually of tin, is 18 inches long and ¾ inch in diameter. Fastened to one end are four triangular pieces of tin, on which the tube rests in an upright position. The shape of these "feet" is such as to raise the end of the tube about ¼ inch from the jar bottom, permitting an even escape of water and causing it to rest automatically at the lowest point in the center of the jar. The rubber tube from the water supply is inserted in the upper end of the metal tube, and the flow of water is controlled by the petcock. In place of this metal tube a glass tube, connected with the water-supply petcock by a rubber tube, may be used, in which case the desired level of the tube in the jar is regulated by the length of the rubber-tube connection.

Another type of tube has been pronounced as more efficient. It is approximately 18 inches long and ¾ inch in diameter; at the bottom is a cone 3½ inches long and 2½ inches in diameter at the base. Three legs are soldered to the cone to keep it about ¼ inch from the sides of the glass jar and to permit the water to escape. The theory is advanced that this cone reduces the velocity of the water at its outlet and does not cause the eggs at this point to be set in rapid motion, as is done when the straight tube is used. The velocity of the water apparently does not affect the eggs while they are in the tender stage, and for this reason the cone tubes have not come into general use.

PREPARING JARS FOR OPERATION

In preparing the McDonald jar for work the side tube is fitted first. The glass tube should be wet, the gum washer slipped on the tube about an inch from the end and introduced into the opening. Holding the tube perpendicularly to the face of the plate, press fairly on the tube, and the washer, rolling on itself, will fall into the seat provided for it. Screw on the binding ring, and test by seeing that the tube slides freely back and forth in the stuffing box; if not, it should be refitted with a heavier or lighter washer, as may be required. Glass tubes of absolute uniformity in size can not be procured. Water is the only lubricant that should be used about the jar fittings.

The jar after being washed clean is filled with fresh water. A shallow tin funnel with a perforated rim is inserted, so that the water will stand as high in the funnel throat as possible.

The requisite number of eggs being in the jar, it is put in position and closed, care being taken that both the inlet and outlet tubes slide freely in their stuffing boxes. If the tubes become gummed, let water trickle down around the binding screws. To close the jar, turn on the water, place the feed tube in the jar, and turn off the water immediately after the feed tube has passed beneath the surface of the water in the jar, thus expelling all the air from the feed tube; otherwise it would rise in bubbles, throwing a portion of the eggs out through the outlet tube.

With a proper quantity of semibuoyant eggs in the jar and the water turned on and regulated, the movement of the current establishes a regular boiling motion in the mass of eggs, which brings each in succession to the surface. This motion may be regulated without altering the quantity of water. By loosening the upper binding screw of the central stuffing box and pushing the feed tube down until it almost comes in contact with the bottom of the jar the motion of the eggs is increased. If the jar is working properly, the dead eggs when brought to the surface remain on top, forming a distinct layer, and by pushing the outlet tube a suitable distance they are carried off by the escaping current.

When the water is turned on for the first time, the jar should be watched closely until a regular motion has been established. When eggs have stood 15 or 20 minutes in the jar before the water is turned on, they do not readily yield to the boiling motion but tend to rise in a solid mass to the top of the jar. By quickly starting and stopping the current the mass is readily disintegrated. The degree or intensity of motion of the eggs varies not only with their age and condition, but also with the condition of the water. If the water is muddy, the motion should be rapid enough to prevent mud settling either on the eggs or in the bottom of the jar. Ordinarily the best motion is that which readily brings the dead eggs to the surface. After the hatching has progressed far enough to dispose of a portion of the eggs there is less resistance to the current, and it should be reduced by shutting off part of the supply or by slightly lifting the central tube. If the motion is not reduced from time to time as the hatching progresses, shells will be carried over into the receiving tank with the fish and, being very light, will be drawn against the outlet screen, causing an overflow. The motion should be so gentle at the time of the greatest hatching as barely to induce the fish to swim out of the jar and leave their cast-off shells behind.

If the connection of the jar must be broken, it is essential that the rubber feed tube does not drop down and siphon the eggs from the jar.

In reconnecting, the air may be expelled with the metal top screwed down in position. To effect this, draw both glass tubes up to the top of the jar and turn on a full head of water, when the air will be forced out in bubbles above the eggs, the bubbles escaping through the outlet tube. The central tube is now restored to its former position. The automatic action permits entire separation of bad from good eggs, though some days may be required to accomplish the full result. The dead become lighter from gases arising from decomposition. A net small enough to enter the mouth of the jar easily and fixed to a handle several inches longer than the jar is convenient for removing particles of foreign matter.

At the approach of the hatching period a careful watch must be kept on the screens guarding the overflow in the fry tanks to prevent clogging through an accumulation of eggshells carried over from the hatching jars. The application of a stiff brush to the inner surface of the screen is the best way to overcome this difficulty. Usually a surplus quantity of the shells will remain in the jars, forming a cloudlike layer above the moving mass of eggs. This may be eliminated from the McDonald jar by manipulating the outlet tube, as already indicated, or, in the case of the open-top jars, by the siphon described below.

In the case of the Chase or other type of open-top jar the eggs are installed in the manner described. The tube through which water enters is inserted and the flow regulated at the petcock, to give the desired motion to the eggs. For the removal of dead eggs and shells a piece of rubber tubing is used as a siphon. A short piece of glass tube is inserted in the end of the rubber tube to be introduced into the jar.

Shad eggs are semibuoyant. The usual period of incubation is from 6 to 12 days in a water temperature 52 to 65° F. These figures represent very nearly the limits of temperature range for the successful incubation of shad eggs. In a temperature of 50° the incubation period is prolonged to 12 days, while at 75° it is shortened to 3 days, but in neither case can healthy fry be produced. While water temperature appears to be the governing factor in the incubation period, other circumstances, not well understood, may also have an influence. Continuous dark and cloudy weather appears to retard and strong light to accelerate development.

When hatched, fry are about 0.37 inch long. They have been measured at intervals of from 5 to 15 days, from late in May to the middle of October. Toward the middle of August the rate in growth diminishes. When 9 days old, they are about 0.62 inch long. Fry 0.5 inch long July 20 were 0.75 inch long 8 days later; on August 14, 2 to 2.25 inches; September 20, 3 to 4 inches; October 1, 4 to 4½ inches; November 4, 5 to 7 inches. Some years they grow faster than others, and in some streams more rapidly than in others. From the State fishponds at Raleigh, N. C., 33 were removed in November, 1884, which measured 8 to 9 inches. Their usual size in the Potomac in the fall is 3 to 4 inches.

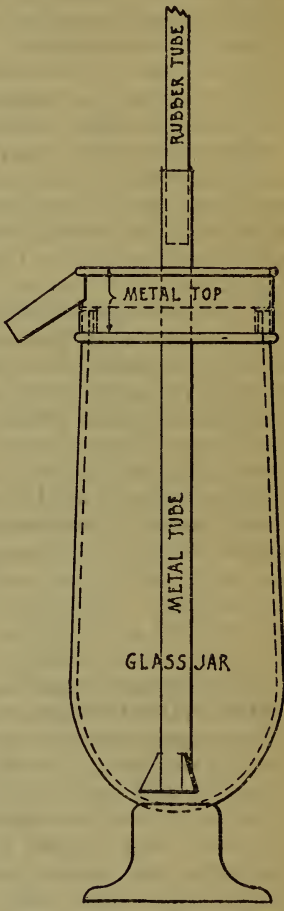

FIG. 8.—Chase open-top hatching jar

MEASURING THE EGGS AND FRY

To estimate the number of eggs and young fry was for years rather a difficult matter to accomplish satisfactorily. The standard made use of at the outset was undoubtedly much too high. The scale most used at present is a light square, made of wood, the longer leg being 15 inches and the shorter 7½ inches long (fig. 8). The material is ½ inch wide and ¼ inch thick. The graduations are on the longer leg and read from the lower end upward The first line is at a height corresponding to the level attained in the jar by a measured half-pint of water, and the succeeding lines are determined by the introduction of additional half-pints of water. When the scale is being constructed, the central glass tube is stopped at the lower end, that it may displace an amount of water equal to the amount of eggs it will displace in practice. Each line on the measuring stick registers 7,000 shad eggs. The number of eggs in a liquid pint is established by actual count. The eggs are at rest when measured.

The jar contents are determined by placing the short leg of the measuring stick over the top, with the other pointing downward and touching the side of the jar. The number is indicated on the scale at the point opposite the surface of the bulk of the eggs. Scarcely any semibuoyant eggs die, under proper conditions, after hatching has commenced, and a close approximation to the number of fry may be obtained from the last measurement, which is made after the careful removal of all dead eggs and the bursting forth of the first young.

FEEDING AND REARING

The young shad swims vigorously, by rapid and continuous vibration of the tail, from the moment it leaves the egg. It is colorless, transparent, and gelatinous. Several hundred in a dipper are scarcely discernible. It has a relatively large yolk sac, but supports it with ease during the first 4 or 5 days after hatching, the small quantity remaining after this time not being visible externally, although found in shad fry 14 to 16 days old. Minute conical teeth make their appearance on the lower jaws and in the pharynx about the second or third day after hatching. The jaws at 3 months are armed with teeth slightly curved.

Young shad feed on other minute organisms, such as exceedingly small crustaceans. Food has never been observed in the alimentary canal until 10 or 12 days after the young fish had left the egg. At about the middle of the second week considerable may be seen, but the intestine is then not often very densely packed. At the age of 3 weeks an abundance of food is found. They have been known at this early age to eat their own kind, and later the young carp and salmon. When cold, raw winds drive the crustaceans into deeper water, the young shad follow them, and in aquaria they take Crustacea freely. In salt-water aquaria they may be fed upon chopped oysters and canned herring roe.

Experiments with young shad were carried on for several years at Central Station in salt-water aquaria. On one occasion about 250 were received in October, at which time they were about 5 months old. They were put in brackish water (specific gravity 1.005), which was added to from day to day for nearly a week, when it was brought up to 1.018, or the same specific gravity as that of the water used in the marine aquaria. At the time that these were placed in the brackish water others were put into fresh-water aquaria, but the latter died within 3 days. Those in salt water began in 2 or 3 days to take food, consisting of chopped oysters, clams, and beef, the preference being for oysters. At first they would take food only when it was sinking, later they began taking it off plants where it had lodged, and finally from the bottom. Nearly all remained healthy, plump, and active for 6 months, some living until about midsummer.

For a number of years two or three million shad fry were reared annually at the fishponds, Washington, D. C. A 6-acre pond was used, the water supply being taken from the city waterworks. The depth was from 2 to 3 feet, and throughout the whole extent there was a dense growth of water plants, among which crustacean food multiplied, new supplies being brought in from the water pipes. Fingerling shad are so tender that the numbers annually liberated could not be ascertained. They can not stand the handling consequent upon counting, not even undergoing transfer in dippers of water, and their scales drop off on being touched. Consequently, at high tide they were liberated into the Potomac through a sluice gate with an outlet pipe about 2 feet in diameter. They required some days to make their escape. By conservative estimate 50 to 60 per cent were safely held until about October. Owing to the difficulty in obtaining suitable rearing ponds, and the necessity of providing the ponds with a water supply that will produce sufficient natural food, the Bureau of Fisheries prefers to liberate the young shad, soon after hatching, on their natural spawning grounds.

TRANSPORTATION

Good, healthy fry will pass from the jar to the collector tank as fast as hatched; they sometimes crowd on the side nearest the strongest rays of light. As many as 500,000 to 800,000 are collected in each tank. In transporting they must be kept in vessels with a smooth surface, about 2,000 to 3,000 fry to a gallon of water. The water in the cans must be well aerated and kept at 58° to 65°, though in rivers and ponds the fry endure a temperature of 80° F.

For a number of years the bureau followed the policy of making plants of shad fry regularly in most of the important shad streams of the Atlantic seaboard, but the results did not justify a continuance of such efforts, partly, at least, because of conditions mentioned herein. Finally, in order to maintain the diminishing numbers at points where artificial propagation is conducted, it has been found advisable to discontinue all shipments of shad eggs or fry to outside points and to return the entire product of the hatcheries to local spawning grounds.

The inadequacy of supply in waters where shad are now propagated makes it impracticable to distribute eggs or fry to other areas. It is important that the fishery be rehabilitated, and to do so more adequate conservation measures must be provided by the individual States.

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